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Design and Flight Test of a Prototype Range Control Module for an 81-mm Mortar

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Design and Flight Test of a Prototype Range Control Module for an 81-mm Mortar

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Abstract

The primary purpose of the Light Forces Program is to improve the effectiveness of fire from the infantry mortar. Advances in microelectronics, sensors, and power supplies make it possible to design and build a miniature, one-dimensional, range correction module (RCM) for the mortar. This report focuses on the flight testing of an RCM prototype device for the 81-mm mortar. The objective of testing the concept was to demonstrate the structural integrity and the drag authority of the design. Based on the experimental data, it can be seen that the undeployed range control modules do not affect the overall drag of the projectile. It can also be seen that when the RCM deploys, it has a significant effect on range. Experimental data obtained from the test indicate that the undeployed RCM does not change the ballistic characteristics of the shell; however, when deployed, the RCM does provide a significant method of controlling range.

ACKNOWLEDGMENTS

The authors wish to express gratitude to those people who contributed to the success of the program. The people of the Aberdeen Test Center, under the direction of Eric Rajkowski, are to be recognized for conducting the firing test. In addition, those who aided in the design and fabrication of the electrical and mechanical hardware are appreciated. Keith Dougherty and William Pennington are to be praised for their expertise in fabricating the mechanical hardware. Finally, Eugene Ferguson and Craig Myers are to be commended for their design work and electrical fabrication.

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1. INTRODUCTION

The primary purpose of the Light Forces Program is to improve the effectiveness of fire from the infantry mortar. Advances in microelectronics, sensors, and power supplies make it possible to design and build a miniature, one-dimensional, range correction module (RCM) for indirect fire weapons, i.e., mortar and artillery. The Advanced Munitions Concepts Branch of the Ballistics and Weapons Concepts Division, Weapons and Materials Research Directorate of the U.S. Army Research Laboratory (ARL), has been doing design work in the area of self-correction devices for artillery since 1996. Recent reports such as "Low Cost Competent Munitions (LCCM) Self-Correction Devices—An Initial Study and Status" and "Preliminary Design of a Range Correction Module for an Artillery Shell" demonstrate the branch's interest in improving the ballistic accuracy of artillery projectiles (D'Amico 1996; Hollis 1996). The design of the RCM has been patented under U.S. Patent No. 5,762,291.

This report focuses on the flight testing of an RCM prototype device for the 81-mm mortar. The objective of testing the concept was to demonstrate the structural integrity and the drag authority of the RCM design. Since these were the main objectives, the amount of electronics and their complexity was kept to a minimum. The concept was demonstrated using a fixed value timing circuit powered by nickel-cadmium batteries. The timing circuit allows the drag mechanism to be released at a predetermined time in flight.

2. BACKGROUND

Figure 1 shows a simplified error "budget" for a typical indirect fire ballistic weapon system. The ellipse represents the impact area of the projectile. The major axis of the oval depicts range error, whereas the minor axis symbolizes the error attributable to deflection. The intent of the RCM is to reduce the range error to about that of the deflection error, thus providing a simple smart munition capability which increases lethality. The RCM is placed between the mortar projectile body and the fuze. The fuze does not require modification and maintains normal fuze function. The module is designed to minimize effects on the aerodynamic characteristics of the projectile. Miniaturization of the device is imperative in order to reduce the impact in logistics and cost. Figure 2 depicts a model of an 81-mm, M889 mortar with a point-detonating M935 fuze, and Figure 3 displays the same mortar with the RCM.

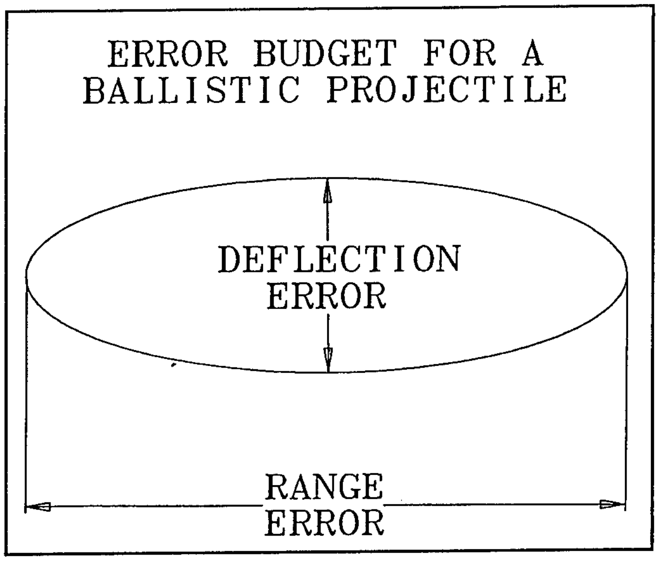

Figure 1. Error "Budget" for a Ballistic Projectile.

Figure 2. An M889 Mortar With a Standard Point-Detonating M935 Fuze.

Figure 3. An M889 Mortar and M935 Fuze With a Range Correction Module.

A booster cup, which normally screws into the fuze, now screws into the module opposite the fuze. A small hollow tube, which runs down the center of the device, allows the ignition flame from the fuze to ignite the charge in the booster cup. Enhancement of this process may be necessary, but it is unknown at this time.

Extending the fuze, as seen in Figure 3, may have some effect on the aerodynamics of the projectile, but the design should maintain the existing ballistic coefficient. The aerodynamic effects were minimized by designing the RCM with a cylindrical shape. The diameter of the cylinder is equal to that of the largest diameter of the fuze.

Figure 4 shows a detailed view of the RCM in the deployed configuration. Depicted are small flat planar surfaces or flare tabs. The effect in flight is to create more drag on the projectile. A more definitive explanation of an RCM concept for a mortar is as follows. The device is attached to the projectile between the body and the fuze, while in the field. An on-board central processing unit (CPU) is preprogrammed with the target location and the firing location coordinates. The mortar is then aimed to fire beyond the target location. An on-board inertial measurement unit (IMU) will determine the range error with respect to the target while the projectile is in flight. The CPU predicts the amount of excessive range that the shell will have. At a certain time in flight chosen by the CPU, the flare tabs will deploy to correct the "over-shoot," thus reducing the range error aspect of the flight.

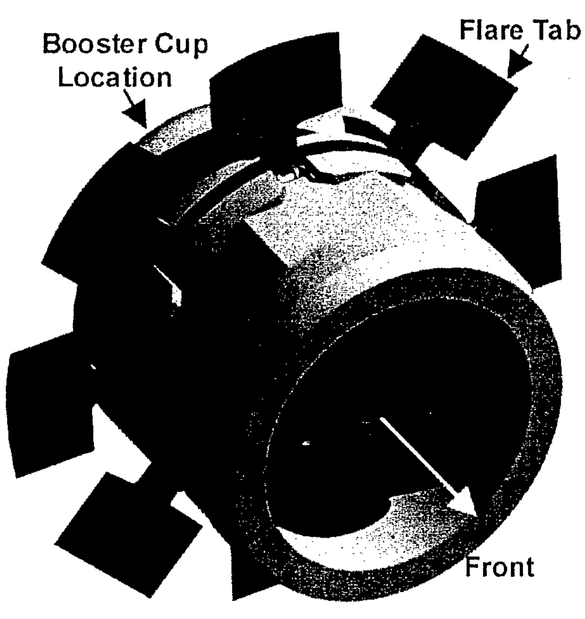

Figure 4. Detailed View of the Deployed Range Correction Module.

3. DESIGN

3.1 Mechanical Design

The prototype mechanical design consists of many parts, several of which are spring loaded and moving in concert. Figure 5 displays an exploded view of the prototype design.

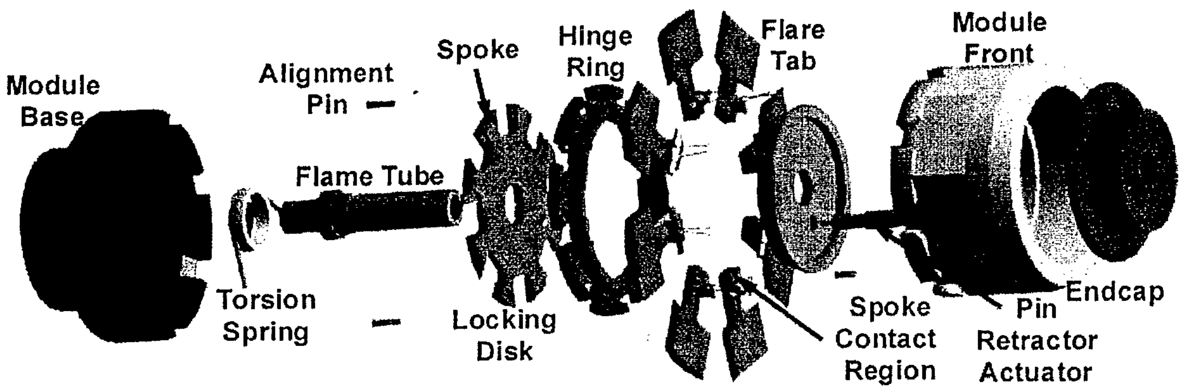

Figure 5. The Exploded Assembly View of the Prototype Range Correction Module for a Mortar.

Installation into the mortar body is simple since the module base has the same threads as a standard fuze. The assembled device extends the fuze from the body by 1.6 inches (40.6 mm).

During a launch, the stacking approach used to assemble the device carries the set-back loads. Alignment pins maintain proper positioning of the module base, the hinge ring, and the module front. The flame tube is crucial to provide support during the rebound loads and the balloting loads of the launch. One end of the flame tube threads into the module base, whereas the other end threads into the end cap. As the end cap turns about the flame tube, the entire assembly is clamped together.

Eight flare tabs provide the actual means of range correction by increasing the overall drag of the projectile when deployed. The flare tabs are originally locked in place, flush with the module front, as seen in Figure 3. In this position, the tabs create a cylindrical surface that will have the least effect on the aerodynamics of the projectile. The flare tabs are locked by means of an internal locking disk, as seen in Figure 5. The spokes of the locking disk push on the underside of the flare tabs. The locking disk is pre-loaded via a torsion spring. The pin of the pin retractor actuator, which is an electro-explosive device (EED), maintains the locking disk in the pre-loaded or locked position. At the desired time in flight, the pin retractor actuator will retract its pin, freeing the locking disk and allowing it to rotate. The flare tabs, which are also individually

spring loaded, will rotate through the slots in the locking disk. As the flare tabs pivot to the deployed 90°, the spokes of the locking disk, which are beveled, will slide under the flare tabs. This locks the tabs in the deployed position. This prototype, however, is not a final solution. Smaller clock-like mechanisms could be designed to allow more room for electronics.

This report focuses on one specific RCM concept and its flight test. Detailed mechanical design of the flare tab mechanisms, the electronics volume, and the structural analysis of the overall design are presented in ARL-MR-411 (Hollis 1998).

3.2 Aerodynamic Analysis

The largest error in munition precision is the range error. Figure 6 displays the errors for range and deflection for the 81-mm, M889, high explosive (HE) mortar projectile. It can be seen that the range error is more than double the deflection error.

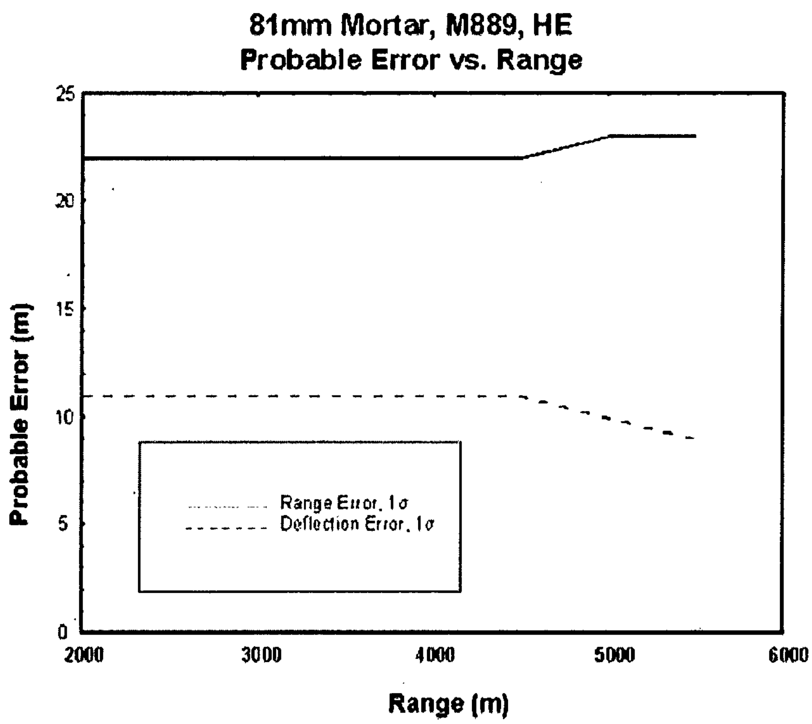

Figure 6. Range and Deflection Errors.

A comparison of the ballistic trajectories of both the standard and modified projectiles is a means of determining range control authority of the RCM. One must compare the trajectories of projectiles during the time of deployment to the time of impact. Initially, a ballistic match

between pre-deployed, modified, and standard projectiles is necessary. A ballistic match between two projectiles requires equal ratios of drag to mass. The cylindrical geometry of the pre-deployed RCM has little or no effect on drag, provided the projectile does not yaw more than 5°. Therefore, the masses of both the unmodified and modified projectiles must be nearly the same. At the time of flight testing, the masses of the modified and unmodified projectiles did not vary significantly.

The drag and aerodynamic coefficients for a projectile with an RCM were derived through the use of an empirical/theoretical computer program (projectile design and analysis system [PRODAS]). Notice that in Figure 7, C_D for the subsonic region of the deployed RCM is approximately 0.52, compared to 0.13 for a standard or undeployed, modified projectile.

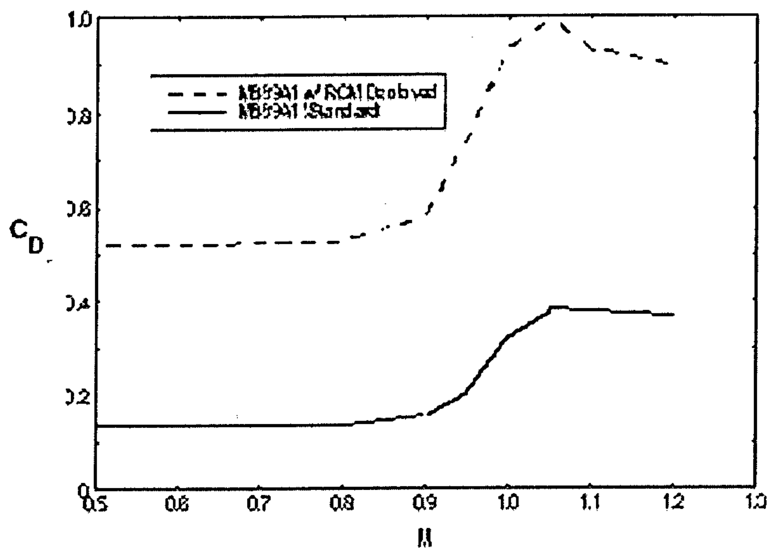

Figure 7. Drag Coefficient Versus Mach Number.

Knowing the predicted drag of the projectile for both undeployed and deployed RCMs and using a six-degree-of-freedom (6 DOF) simulation program, one can predict the range of the projectile for any time of deployment of the RCM. For the purpose of the simulation, a 15-second deployment time, a quadrant of elevation of 891 mils, and a muzzle velocity of 304 m/s were chosen. Using these values, we predicted a 750-meter difference in range.

The electronic timers of the prototype RCMs were set as close to 15 seconds as possible. Because of minor variations in the clock frequency, the deployment times fell short of the desired value of 15 seconds, varying from 14.04 to 14.6 seconds. Using the computer model, we

calculated the predicted ranges for the delay values for each of the RCMs. Figure 8 displays the predicted ranges for the five RCMs that were fabricated. The nominal range of the M889A1 under the same conditions is 5700 meters (TACOM-ARDEC, June 1997).

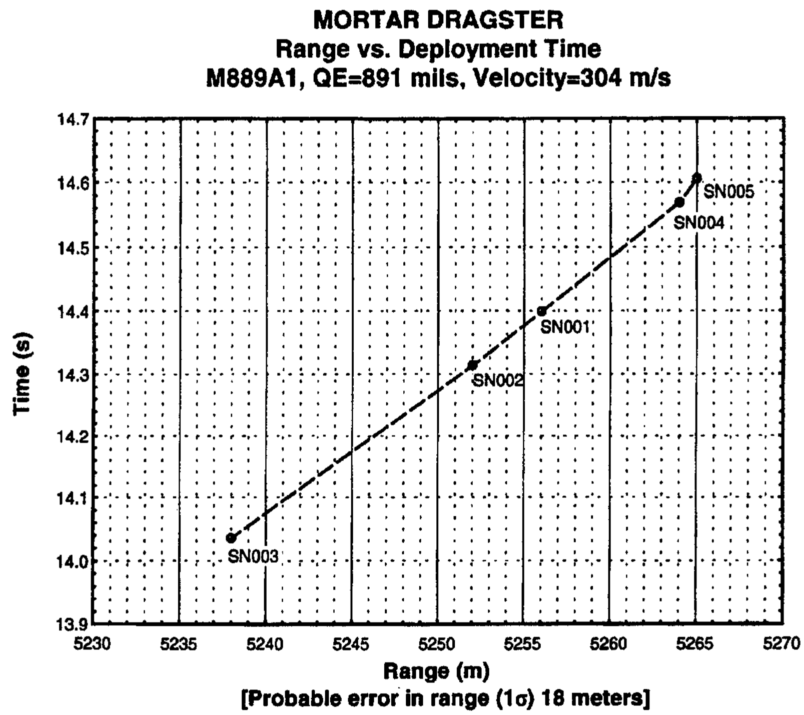

Figure 8. Predicted Range Versus Deployment Time for the Five RCMs.

4. ELECTRICAL DESIGN

The electronics contained in the RCM had two functions. The first was to activate the electronics at launch, and the second was a timing circuit to fire the EED at a predetermined time in flight.

The activating circuitry consisted of a g-switch and a silicon-controlled rectifier (SCR) switch circuit. The g-switch was a 1000-g momentary contact type made by Aerodyne Controls Corporation. This switch applied the stimulus at launch, which allowed the power supply to turn on the SCR. Once turned on, an SCR will stay on as long as power is applied to its input. To prevent the loss of power to the circuitry during a momentary battery contact failure, the output of the SCR was fed back to its gate through a storage capacitor. This allowed the circuit to ride through power glitches of as much as 1/2 second.

The timing circuit consisted of an MC14060B complementary metal oxide-silicon (CMOS) counter timer with a clock frequency based on a resistive-capacitive (RC) time constant. By using the Q14 output, the clock frequency of 546 Hz would be divided by 8192, yielding a target firing time of 15 seconds. Because of component tolerances, the times varied from the predicted time. The Q14 output drove a field effect transistor (FET), which fired the EED. Figure 9 shows the circuit schematic.

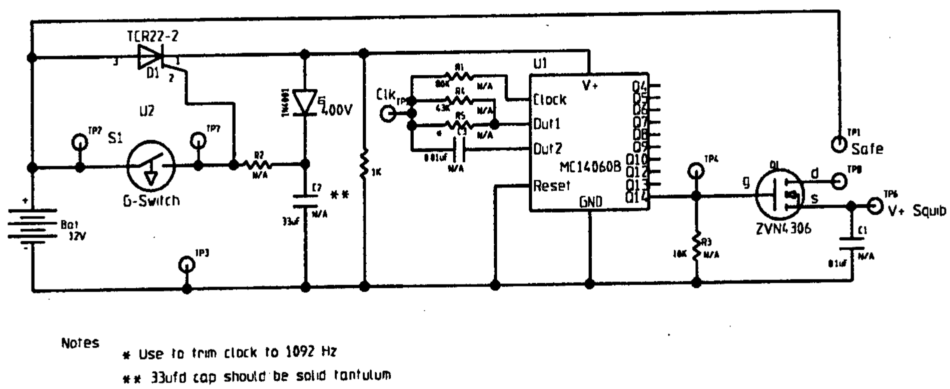

Figure 9. Circuit Schematic.

5. FLIGHT TEST

5.1 Setup

The flight-ready RCM prototype device as shown in Figure 10 is composed of the RCM unit, the long cylindrical projection on the RCM that contains the nickel-cadmium battery pack, and a polycarbonate wind shield filled with electronic components. As stated in the introduction, the intent of the flight test was to determine drag authority and to demonstrate the structural integrity of the design. Therefore, the complexity of the electronic components, including the battery, was kept to a minimum. The exterior dimensions of the wind shield are those of an actual fuze. An M889E1 projectile with an RCM installed can be seen in Figure 11. Some of the inert filler in five M889E1 projectiles was drilled out in order to install the RCM. The physical properties of the modified assembled projectiles did not vary significantly from those of the standard projectile assembly. Five modified M889E1 projectiles were to be fired, in alternating succession, with five M889E1 projectiles that had a standard inert fuze. All projectiles were assembled to Charge 4 propulsion charges and were conditioned at a temperature of approximately 21° C for 24 hours before being fired. A Weibel 1000 tracking radar was used to measure slant range as a function of time, from which the velocity/range history, muzzle velocity, and flight path

data are derived. In order to check the integrity of the RCM, a Kodak 4540 high-speed motion-analysis camera system provided an image of each projectile about 30 feet after the projectile exited the muzzle. Five inert M889E1 rounds (two at Charge 3, 110 mils' quadrant of elevation [QE]; one at Charge 4, 1100 mils' QE; then two at Charge 4 at 891 mils' QE) were fired to seat the base plate and verify proper operation of the test instrumentation. All test cartridges were fired from a ground-mounted M252 mortar at 891 mils' QE. Each RCM was also subjected to an electronic diagnostic test at the firing range before assembly onto the projectile body. During the diagnostic check, it was noted that the timers were faster than when previously measured in the laboratory. The clocks were 0.2 second faster on the average. The RCMs were threaded onto the modified projectile body in place of the fuze and hand tightened (Aberdeen Test Center 1998).

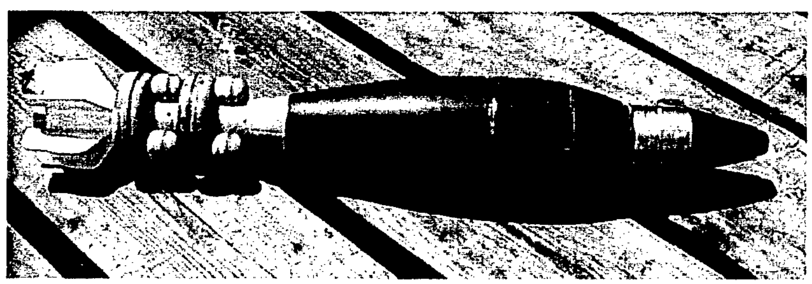

Figure 10. RCM Assembly. Figure 11. M889E1 Projectile With Charge and RCM Installed.

5.2 Results

Physical properties of all five RCMs and M889E1 projectile assemblies were obtained and are listed in Table 1. Notice that the combined length of the modified projectiles is 1.6 inches longer than a standard projectile and fuze. In addition, the average weight of the modified projectiles is 9.34 lb, compared to an average standard weight of about 9.28 lb.

Table 1. Projectile Assembly Physical Properties

Round No.	Bourrelet Diameter (in.)		Length (in.)	Weight (Lb) W/Fuze	CG From Base	Moment of Inertia ($lb\text{-}in^2$) Axial	Transverse
1	0° 180°	3.120 3.120	20.86	9.34	11.93	140.692	11.175
2	0° 180°	3.120 3.120	20.86	9.31	11.93	141.2754	11.175
3	0° 180°	3.120 3.120	20.89	9.37	11.94	141.0809	11.246
4	0° 180°	3.120 3.119	20.90	9.33	11.93	141.5673	11.246
5	0° 180°	3.120 3.120	20.86	9.33	11.93	140.4005	11.246

Even though five RCMs were intended to be tested, only four were flown. During the flight test, the first two RCMs did not deploy. A playback of video from the Kodak 4540 indicated RCM sound structural integrity during launch. It was then decided to fire two more RCMs and reserve one unit for test under laboratory conditions with an IMPAC shock table. Only one of the last two devices deployed. Table 2 displays the flight data of the projectiles that were fired. Notice the similarity of the ranges for the modified projectiles and the standard projectiles. More importantly, notice that the change in range on the projectile that deployed the RCM is on the order of 850 meters.

Figure 12 is a plot of the radial velocities of the first control round (001) and the RCM (006) that deployed. Note the change in velocity that occurs at about 13.8 seconds, which was the predetermined time for the deployment. Figure 13 displays the dramatic change in drag for the deployed RCM. The drag coefficient for that RCM was 0.48. In addition, notice how similar in drag the failed RCMs are to the control rounds. The drag coefficient for both the undeployed RCM and standard projectiles is about 0.13.

Table 2. Projectile Flight Data

Round No.	Muzzle Velocity (m/s)	Time of Flight (sec)	Range (m)	Deflection (m)	Comment
1	300.95	40.62	5744.32	-99.83	Standard
2	298.75	40.28	5667.00	-121.60	Fail
3	301.33	40.76	5769.16	-111.11	Standard
4	300.63	40.61	5698.49	-114.76	Fail
5	301.13	40.79	5762.89	-115.77	Standard
6	299.89	42.19	4841.55	-84.05	Deploy
7	301.99	40.85	5770.50	-90.70	Standard
8	300.66	40.68	5692.89	-121.37	Fail

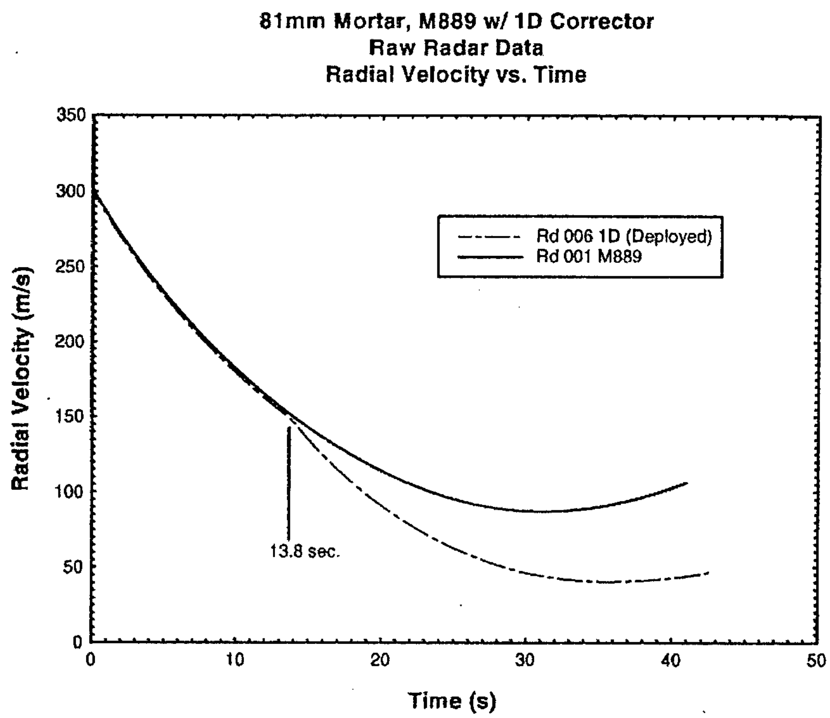

Figure 12. <u>Radial Velocities of First Control Round and RCM That Deployed</u>.

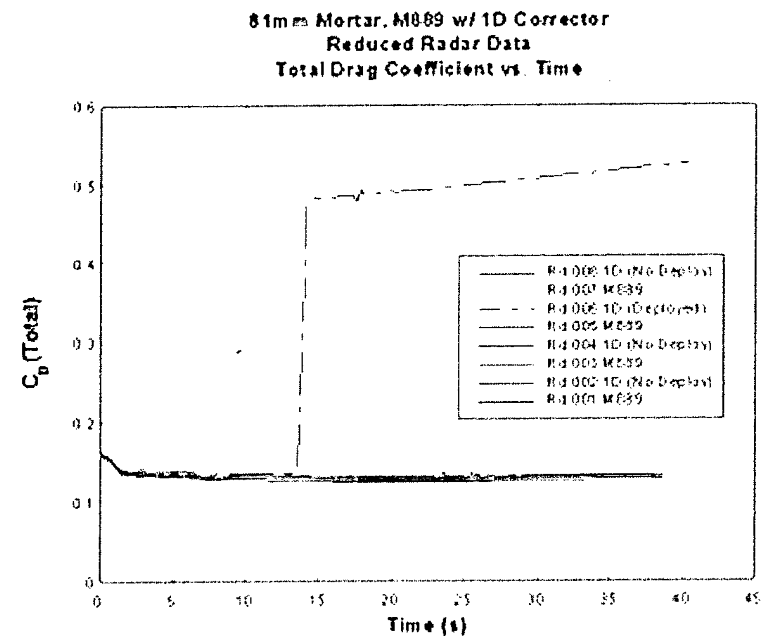

Figure 13. Change in Drag for the RCM That Deployed.

5.3 Failure Analysis

In an attempt to determine the cause of malfunction, the authors subjected the remaining RCM unit to a series of tests. The device was first photographed with X-rays at various points of view and intensities in an effort to ascertain anything peculiar. Since several electrical test points were built into the RCM, electrical diagnostics were also performed. Everything was verified, which led to placing the device in a fixture and subjecting it to an axial shock load equal in magnitude to that of the set-back load for the M889E1 mortar projectile. The device had been previously tested on the shock table with shock loads as high as 15,000 g's for 0.0001 second. However, the entire assembly, including g-hardened electronics, had not been shocked. With electrical leads now attached to the test points, the RCM was shocked with approximately 12,000 g's. Almost 15 seconds later, the flare tabs deployed. The resulting deployment of the device left the cause for the three malfunctioning RCMs undetermined.

6. CONCLUSION

A design study and flight test demonstration were conducted to determine the range control authority of a simple range control module. The module was designed to be added to a mortar shell without requiring modifications of the components. The studies indicate that it would be possible to mechanically change the drag at desired times during a flight to significantly shorten the normally

expected range. Based on predicted data and a detailed metal parts design, five RCM units were built and flight tested. Of the four units that were fired, only one functioned as planned.

Although one successful deployment may not completely validate this experiment, it does provide insight to the amount of range control that can be accomplished. The experimental drag coefficient obtained from the one round of 0.48 (see Figure 13) is slightly less than the predicted value of about 0.52 (see Figure 7). The mortar shell achieved an 850-meter reduction in range when its RCM deployed at 13.8 seconds. Unfortunately, detailed examination of the unfired RCM unit failed to provide any information as to why three of the flight units did not deploy.

Based on the design study and the test data obtained, it can be seen that the undeployed range control modules with the mortar shell had very little effect on the overall drag of the projectile. It can also be seen that when the RCM deploys, it will have a significant effect on range, depending on the time of deployment.

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REFERENCES

Condon, J.A., and M. Hollis, "Dynamic Analyses of the Mortar Dragster Tab Mechanism," ARL-TN-107, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, April 1998.

D'Amico, W. "Low Cost Competent Munitions (LCCM) Self-Correction Devices—An Initial Study and Status," ARL-TR-1178, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, August 1996.

Hollis, M. "Preliminary Design of a Range Correction Module for an Artillery Shell," ARL-MR-298, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1996.

Hollis, M. "Design and Analysis of a Prototype Range Correction Device for a Mortar Projectile," ARL-MR-411, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, August 1998.

Arrow Tech Associates, "PRODAS (Version 3.9)," Copyright 1990-1995.

US TACOM-ARDEC, "Firing Tables for Mortar, 81-mm, M252," FT 81-AR-2, Firing Tables and Aeroballistic Branch, June 1997.

Rajkowski, Eric. "Test Record," Test Record No. LS-00208, TECOM Project No. 2-MU-001-RCD-001, U.S. Army Aberdeen Test Center, Aberdeen Proving Ground, MD, August 1998.

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The primary purpose of the Light Forces Program is to improve the effectiveness of fire from the infantry mortar. Advances in microelectronics, sensors, and power supplies make it possible to design and build a miniature, one-dimensional, range correction module (RCM) for the mortar. This report focuses on the flight testing of an RCM prototype device for the 81-mm mortar. The objective of testing the concept was to demonstrate the structural integrity and the drag authority of the design. Based on the experimental data, it can be seen that the un-deployed range control modules do not affect the overall drag of the projectile. It can also be seen that when the RCM deploys, it has a significant effect on range. Experimental data obtained from the test indicate that the undeployed RCM does not change the ballistic characteristics of the shell; however, when deployed, the RCM does provide a significant method of controlling range.

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